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Hydraulic Approach to Flush Systems for Dairy Manure Removal

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Abstract. The following note characterizes the hydraulic behavior when removing manure from alleys through the flush system in dairy freestall barns. The flush system guarantees the moving, the conveyance and the removal of manure from the alleys flooring, depending on the main manure flux characteristics. The application of the Chezy's formula, using the Manning expression for the Chezy coefficient, to calculate the mean flush flow velocity is investigated to outline the importance of the proper adjustment of the value to be attributed to the alley roughness, which depends on both the flooring material and the manure quantity on the flooring. Experiments on a freestall barn, located in the Reggio Emilia in the North of Italy, which has been using this cleaning system for some years, have been performed to calculate the Manning coefficient n values once it was known the flow flush velocity. Differences in the quantity and type of solid materials laying on the floor have been found to strongly influence the roughness of the alley and the variation on the velocity values. Velocity measurements collected during flush operations both on the already cleaned alley and on the alley enriched with manure allowed us to investigate the Manning's coefficient variations depending on the manure presence on the alleys. Differences on measured and calculated velocity values obtained through the application of the Chezy formula are attributed to the choice of the Manning coefficient n value equal to 0.02. The calculated velocity values were always less than those measured, yield an under-estimation of the velocity and then a minor cleaning actions.

Keywords. Dairy freestall, manure removal, flushing, Manning's coefficient

Introduction

Flush systems for removing animal manure from dairy freestall barns are starting to be utilized on Italian dairy farms. It is based on the removing action offered by the flushing of a circulating fluid. A flush system properly designed is able to keep the alleys free of animal manure and ensure a satisfactory degree of cleanness (Elder, 2003). Manure scraping is still a technique widely used in tie-stalls. As regards the freestall barns, the removal action may be carried out through mechanical or hydraulic systems.

Mechanical scrapers or scraping with a tractor are still widely utilized on Italian dairy farms, especially when bedding materials are used. However, the hydraulic systems realized in the channels below slatted floors or on the full concrete alleys are taken into consideration in the design of new freestall barns. Among the hydraulic systems, the evacuation of manure by flushing of recycled slurry is expanding (Barbari *et al.*, 2004).

Scraping requires more manpower and greater handling of material than flushing, and it has, therefore, typically been used only for management of manure from areas that cannot be effectively flushed, such as flat barn and driveways. Some advantages of flushing dairy facilities, compared with mechanical removing actions may be seen in a reduction of labor, the possibility of being automated, an increased reduction of waste and odor presence in the alleys depending on the number of flushings, better conditions for the dry process of the floorings. Among disadvantages include the necessity of an appropriate design of the alleys for the removing action of the manure, the utilization and the storage of large amounts of water, operation problems during low temperatures, installation costs of hydraulic devices (pumps, piping, valves, etc.), the use of a slurry separator to avoid problems of clogging in the hydraulic systems.

The basic hydraulic requirements for flushing dairies are proposed by Fulhage (1993) and he suggests the application of the Chezy formula for the open channels (Chow, 1954) for dairy flushing, considering it adequate on the basis of the US experience. In this note, an experimental study of the analysis of the manure flux in two different alleys of the same dairy freestall barn was performed aiming at the individuation of the changes in the alley roughness depending on the soiling degree of the alleys.

Materials and methods

Freestall barn description

The experiments were carried out in a dairy freestall barn recently constructed and located in the area of Reggio Emilia (North of Italy), producing the Parmigiano Reggiano cheese. A scheme of the flush system is presented in figure 1.

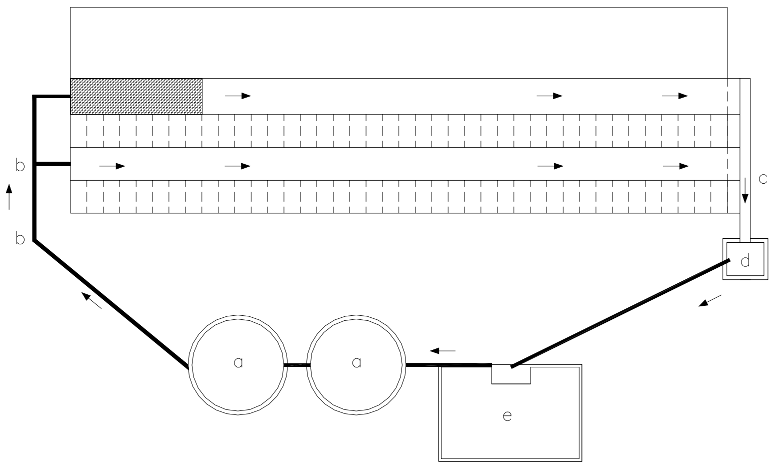

Figure 1. Scheme of typical components in a dairy flush system: a) gravity flush tanks; b) flush valves; c) collecting line; d) tank with recycle pump; e) dung platform with mechanical separator

The principal characteristics of the freestall barn, opened on three sides, are shown in table 1. As regards the alley flooring, longitudinal grooves, 0.02 m wide and deep at a distance of 0.1 m, are able to control the slipperiness when wet. The liquid fraction of the manure for the flushing is collected in an excavated tank and then pumped through a propeller pump; the entrance into the alleys is regulated through flush valves. The liquid solution at the exit of the alleys is discharged into a collecting line and then sent to the tanks. Through a pumping system, the manure is then transferred to a mechanical separator with helical compression; the solid fraction is stocked in a dung platform while the liquid fraction is collected in the first tank, overflowing into a second tank. The flush parameters for the freestall barn are shown in table 2.

Table 1. Freestall barn characteristics

Alley	Feeding alley	Stall access alley
Number of cow places	105	70
Length L [m]	73	58
Width B [m]	3.3	3.14
Slope [%]	1.65	1.5

Table 2. Flush parameters for the freestall barn

Pump power [kW]	Flush flow rate [m^3/s]	Flush valve opening time [s]	Flush operations per day
22	0.22	60	3

Fulhage (1993) suggests to apply the Chezy's formula, using the Manning expression for the Chezy coefficient, to calculate the mean flush velocity value, as:

$$V = \frac{1}{n} R^{2/3} i^{1/2} \tag{1}$$

where:

V = flow velocity in (m/s)
R = the hydraulic radius (m)
i= slope (m/m)
n = the Manning's channel roughness ($m^{-1/3}s$).

The utilization of the above formula is based on the hypothesis of steady state conditions (in particular, uniform flow) along the alleys. Moreover, the application of the formula is affected by the proper adjustment of the value to attribute to the alley roughness, which depends on both the flooring material and the manure quantity on the flooring. Since on tables reporting *n* values for artificial open channels it is quite hard to find a description of such a situation, it is common practice to utilize the value of 0.02, as proposed by Fulhage (1993). He states experience has shown such a value is descriptive of dairy flush alleys under normal manure load conditions. In addition, the physical and chemical characteristics of the flush fluid are changing along the alley due to the dilution effect of the encountered materials laying on the floor.

In this study, experiments were performed to calculate the *n* values from the Chezy formula and then compare those values with 0.02, once it was known the flow flush velocity. Experiments were carried out using an image recording system and digital pictures and the digital material analyzed with image software.

Trials were made on both the alleys, feeding and stall access, in two different months, March and June 2005. In particular, two tests were carried out on the feeding alley, two on the stall access alley and one test on both the alleys just after the regular cleaning operations had been made. The water depth in the alleys was measured using three vertical graduated segments in three different sections along the alley and the mean value obtained. On the alley floor, lime has been put on lines normal to the longitudinal flow, at a distance of 5 m, to evaluate the movement of the wave flux. Image analysis has been carried out to take the flush discharge time when intercepting the back sights created with lime. The velocity of flush water was calculated as the ratio of the alley length and the mean flush time.

The Chezy formula was used to calculate the roughness coefficient once the flush water velocity was known. Different values of the obtained roughness coefficient may be determined depending only on the manure flooring conditions.

Figure 2 and 3 show the flush wave on the feeding alley respectively with and without the manure presence. The pictures depict different characteristics in the regularity of the moving flux on the surface, the advancing front results disturbed by the presence of manure on the floor.

Figure 2. Flush wave on the feeding alley with manure present

Figure 3. Flush wave on the feeding alley without manure present

Results and Discussion

The values of Manning's *n* were determined by equation 1, where velocities and flow depths were measured for each experiment. For the feeding alley, the experiments in March and June offered similar flush velocity, 1.32 and 1.36 m/s respectively with consequent values of *n* equal to 0.0168 and 0.0164. As regards the trial on the alley without animal manure the velocity value was 1.50 m/s and *n* equal to 0.0128. The presence of manure induces a reduction of flush velocity due to an increase of flooring roughness.

As regards the stall access alleys, the experiments in March and June have been carried out under different management conditions of litter quantity, inducing a different load present on the alley when flushing. The velocity value for the March trial was 1.28 m/s and in June 1.02 m/s with *n* values of 0.0166 and 0.0217 respectively. The major quantity of litter and manure on the stall access alley in June provoked a reduction in the flush velocity and a roughness increase of 30% compared to March. The roughness values for the feeding and stall access alleys for the March trials were comparable at least for the three decimal digits.

Aiming at assigning a roughness value to the flooring and its grooves, the flush system has been utilized on the alleys just after the cleaning operations were made, guaranteeing the absence of the manure on the alley. The measured time of the flush wave velocity value for the stall access alley decreased of 10% with respect to the manure presence (March trial) and for the feeding alley the reduction was of 15%. The obtained values for the *n* coefficient were 0.0128 for the feeding alley and 0.0125 for the stall access alley respectively. Since the difference between the two values is on the fourth decimal digit, it may be considered as the roughness of the flooring alley under the condition of manure absence.

As regards the *n* value under the manure presence, the trials showed a recurrent value of 0.016 with weak variations on the fourth decimal digit for both the feeding and the stall access alley. Completely different conditions in terms of manure and litter load on the stall access alley in the month of June induced a strong reduction in the flow velocity value and an increase in the *n* value of more than 30%. Only under such a particular condition, it has been found *n* values reaching the 0.02 found in literature.

To outline the importance of *n* value variations of the third decimal digit, referring to the table reporting the Manning *n* values for artificial channels (Chow, 1959). A value of 0.011 represents concrete channels, a value of 0.020 represents earth channels or masonry channels with lime deposition on the bottom. This means the obtained roughness value for the alley with manure present is quite far from the situation suggested in literature.

Figure 4 depicts the velocity values as obtained by the Chezy formula (Vc) using an *n* value equal to 0.02 and the measured velocity values (V) for the different trials. The straight line represents equal values for the calculated and measured velocity values. Only one value is close to the straight line and then it may be considered well represented by the velocity value corresponding to a 0.02 *n* value. In particular, the measured velocity value equal to 1.02 m/s (1.11 m/s by Chezy) is obtained under particular conditions of litter and manure load on the alley. The value of *n* equal to 0.02 may be considered representative of a situation that is not the current one in the analyzed freestall barn. The use of that *n* value may result from an understimation of the flush velocity in the alley. The farther the points are far from the line the bigger is the difference between the calculated and measured velocity values. In particular, all the points, with the exception of one, are above the line, meaning the measured velocity values are larger than the calculated ones.

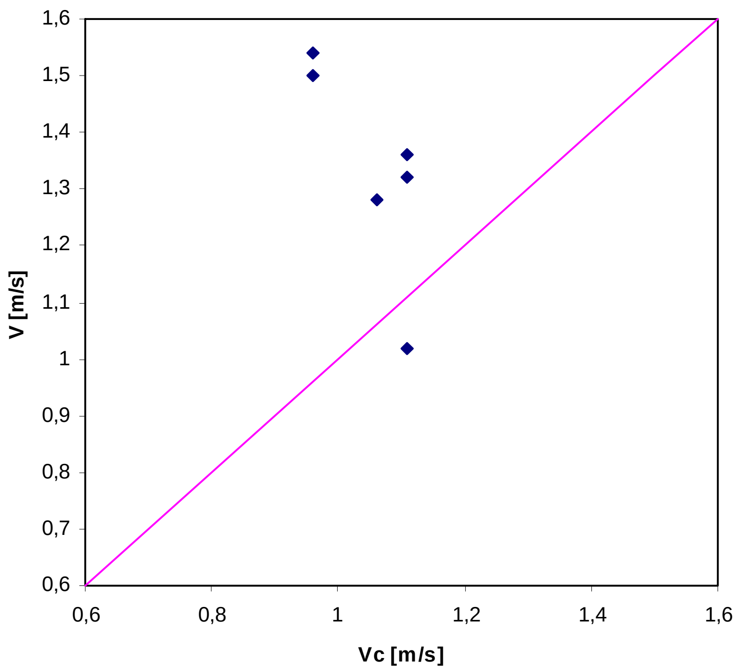

Figure 4. The calculated velocities (Vc) against the measured velocities (V)

Conclusion

A flush system for removing animal manure on the feeding and stall access alleys was experimentally studied in a dairy freestall barn in the province of Reggio Emilia, Italy. The measured flush velocity values were compared with those obtained by the application of the Chezy formula for open channels with a constant value of the Manning roughness *n*, suggested in literature equal to 0.02. Starting from the known velocity values, the Chezy formula was utilized for calculating the Manning' coefficient *n* under different conditions of manure load on the flooring and in absence of manure. The *n* value equal to 0.02 weakly represents the regular conditions of manure presence on both the feeding and stall access alleys in the experimented dairy freestall barn. The obtained values for both the alleys were of 0.016 under regular conditions of manure presence. As regards the flooring roughness under clean conditions, it resulted a *n* value of 0.012. The consequence of these lower obtained *n* values results in an increase of the measured velocity values. Then, the application of the Chezy formula with a constant *n* value equal to 0.02 may result in an under-estimation of the real flush velocity and consequently in the cleaning action of the flush system on the alleys in the analyzed freestall dairy barn. From a design point of view, the use of the constant *n* value of 0.02 may induce variations on the geometric characteristics of the alley to obtain bigger velocity values.

These first experimented results on the couples of measured and calculated velocity values show the importance of the choice of the value of the Manning coefficient *n* and its variation depending on the manure load on the alleys.

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